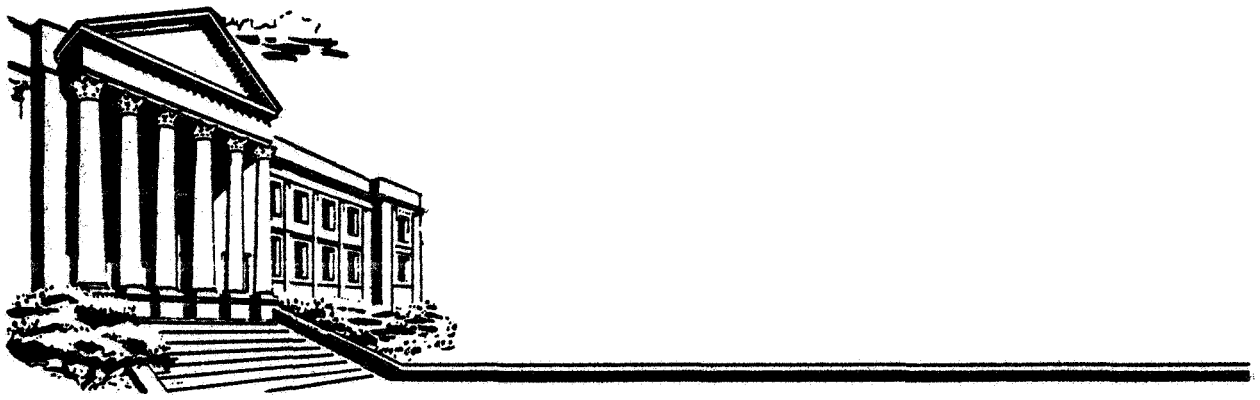

Interim Report

I-B2116-4

EVALUATION OF WEAR AND CONTAMINATION GENERATION OF HYDRAULIC COMPONENTS

by

R. H. Hollinger
G. F. Lare
J. N. Donis

October 1964

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER - NASA
Huntsville, Alabama

Contract No. NAS 8-5372

THE FRANKLIN INSTITUTE
LABORATORIES FOR RESEARCH AND DEVELOPMENT
PHILADELPHIA PENNSYLVANIA

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1.0 Introduction

1.1 This report covers the work performed on Contract NAS-8-5332 during June and July of 1964.

1.2 The results of four test series are reported. They are:

a) Tests of PV006L012 B pumps at an ASTM contamination level of 0 to 1

b) Tests of AP05V-14 pumps at an ASTM contamination level of 5 to 6

c) Tests of PV006L012 B pumps at an ASTM contamination level of 3 to 4

d) Life and efficiency tests of the S-IV servo-actuator filter.

2.0 PV006L012 B Tests, 0 to 1 Level

2.1 This test run employed the remaining two of four PV006L012B pumps. A previous test at a 0 to 1 level had been made on this type pump and was reported in I-B2116-3. The tests were conducted with no difficulty and proved to be uneventful.

2.2 The leakage flows for this test run are shown graphically in Graph No. 1. There was an initial increase in leakage for both test pumps as was noted in previous tests, again, presumably from clearance changes resulting from expansion. After approximately 22 hours of cycling, pump No. 2 (Serial No. MX 71945) showed a sudden increase in leakage flow after which the flow became relatively constant. At approximately 40 hours of cycling another rapid increase in leakage flow for this pump began with a resulting increase in torque (See Fig. 2), but this time showed no inclination to level off. The test for the pump was discontinued at 45 hours. The other test pump was allowed to continue cycling for a total of 55.5 hours.

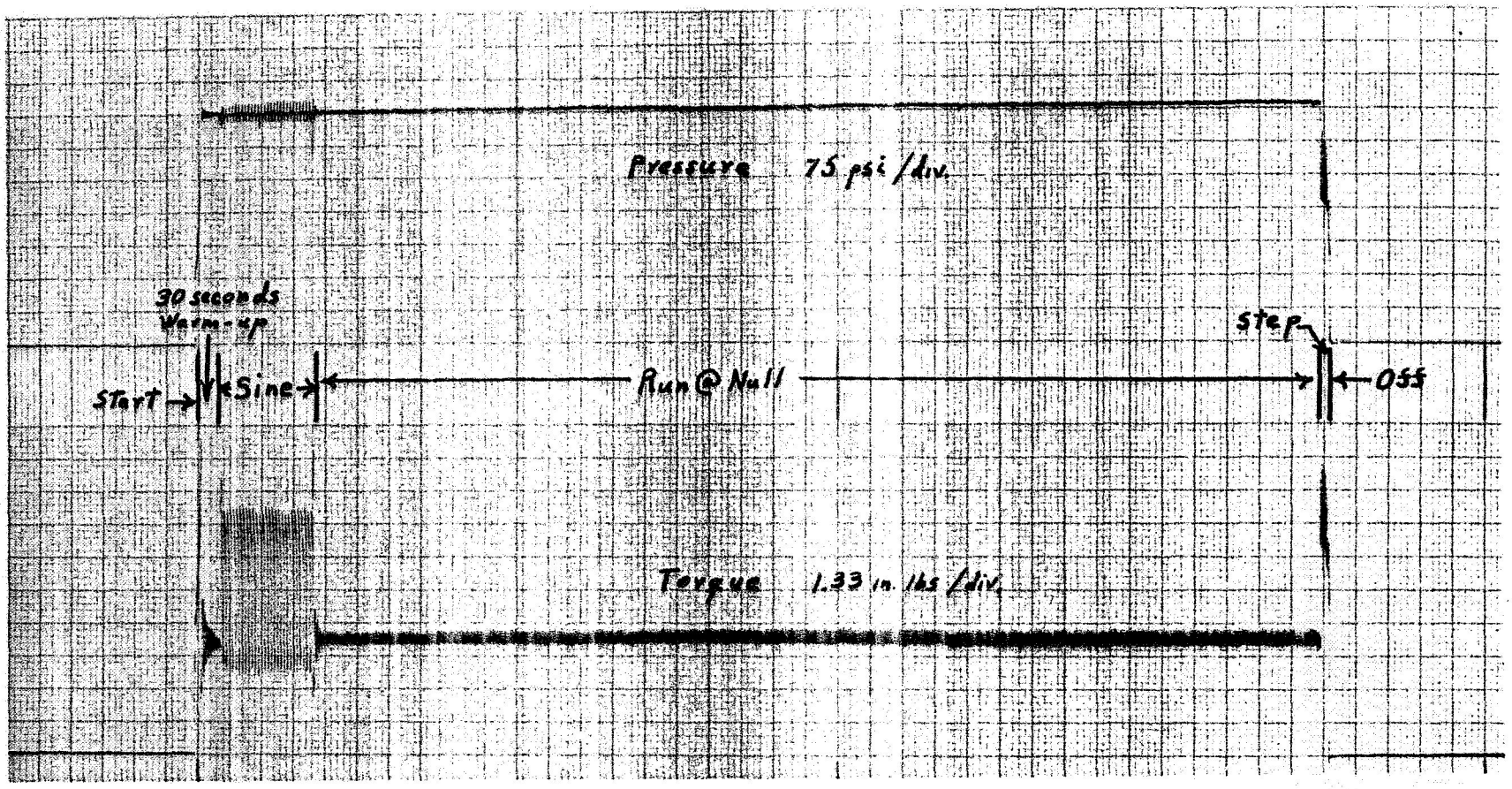

Pressure 75 psi/div.
30 seconds
Warm-up
Start
Sine
Run @ Null
Step
OSS
Torque 1.33 in. lbs/div.

Figure 1

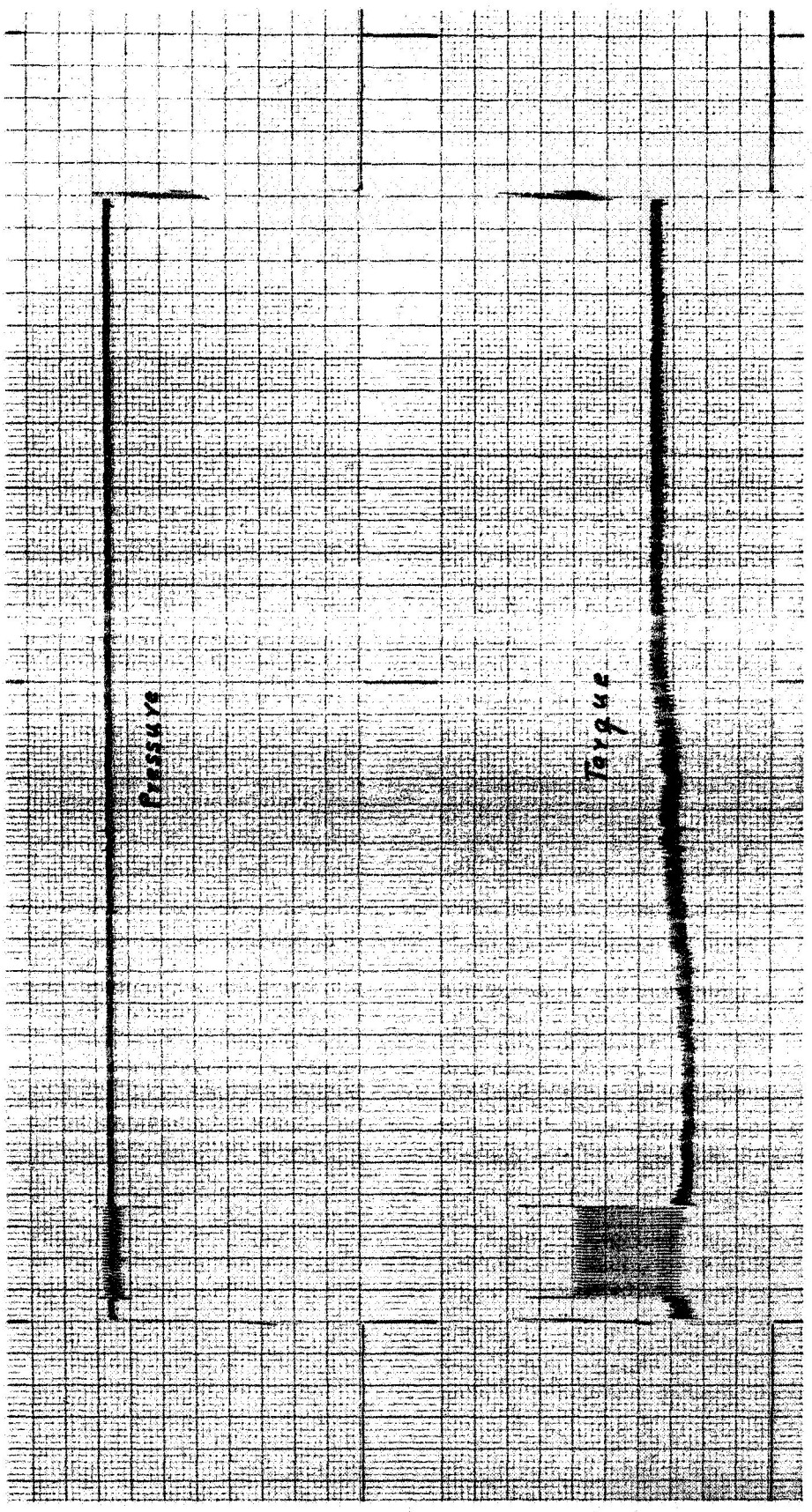
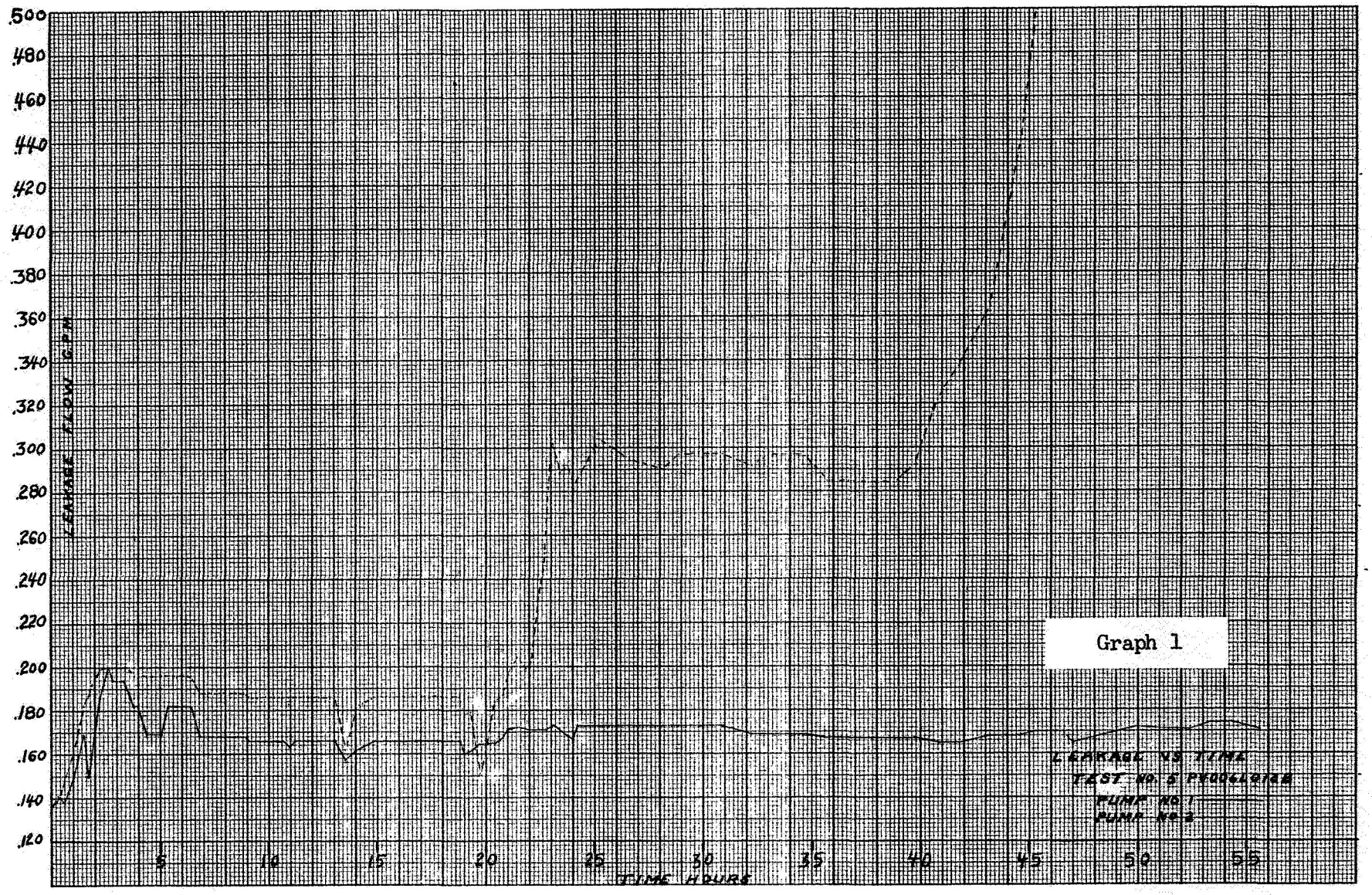


Figure 2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.200
.180
.160
.140
.120
LEAKAGE FLOW GPM
5
10
15
20
25
30
35
40
45
50
55
TIME HOURS
LEAKAGE VS TIME
TEST NO. 5 PROCEDURE
PUMP NO. 1
PUMP NO. 2

Graph 1

(See Figure 1 for behavior and key to cycle.) Since this pump represented the third pump necessary for higher contamination level testing, together with the two pumps which had successfully completed the previous tests, and since the leakage flow was showing no change, the test was discontinued at that time.

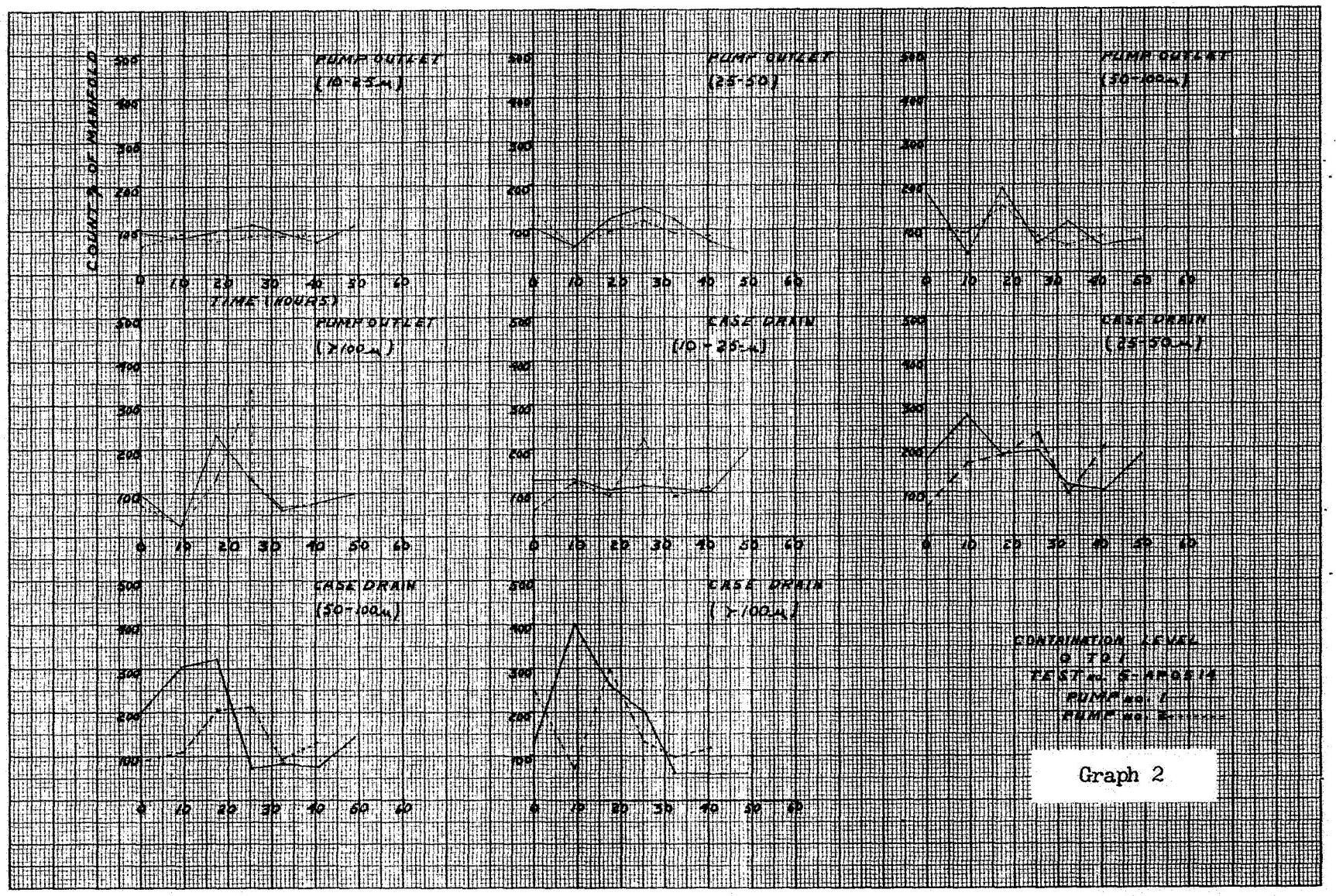
2.3 The contamination counts taken during the tests are shown in Table 1. Table 2 shows the counts expressed as a percentage of input manifold counts and these values are shown graphically as a function of cycling time in Graph No. 2.

3.0 AP05V-14 Tests, 5 to 6 Level

3.1 Three of four AP05V-14 pumps which had completed tests at a 0 to 1 level satisfactorily were selected for this test. The high level was selected intentionally in order that failure of some type would be induced during the test cycle. The pumps chosen were:

	Leakage Flow	
Pump No.	End of 1st Test	Start of this Test
80060	.240 gpm	.260 gpm
80018	.195 gpm	.160 gpm
80062	.185 gpm	.160 gpm

3.2 The test was conducted in the same manner as the low contamination level tests. Maintaining the high contamination level proved to be very difficult since the AC dust contaminant was continually reduced in size from the greater than 100 micron and 50 to 100 micron size ranges. These size ranges were replenished every four hours. It was noted however that depletion of these ranges occurred after only 0.5 hours of cycling. Dust was added to the sump during the "off" portion of the test cycle with the sump circulating system operating.


COUNT % OF MANIFOLD
TIME (HOURS)
PUMP OUTLET (10-25 μ)
PUMP OUTLET (25-50)
PUMP OUTLET (50-100 μ)
PUMP OUTLET (>100 μ)
CASE DRAIN (10-25 μ)
CASE DRAIN (25-50 μ)
CASE DRAIN (50-100 μ)
CASE DRAIN (>100 μ)
CONTAINATION LEVEL
0 TO 1
TEST No. 6-AMOS 14
PUMP No. 1
PUMP No. 2

Graph 2

B2116

Table I

PARTICLE COUNTS

	0 hrs.	9h 22m	17h 32m	25h 37m	32h 32m	40h 37m	44h 2m
10-25 μ							
Pump No. 1	2,504	1908	2,641	1156	996	707	1218
Pump No. 1 Drn.	3,365	2,956	2,894	1175	1141	983	2181
Pump No. 2	1601	2,010	2,061	877	911	862	
Pump No. 2 Drn.	1627	2,803	2,504	2,206	971	1089	
Manifold	2,573	2,215	2649	984	1039	973	1090
25-50 μ							
Pump No. 1	180	81	248	110	228	44	41
Pump No. 1 Drn.	311	338	358	139	210	62	161
Pump No. 2	255	76	189	87	169	51	
Pump No. 2 Drn.	121	207	356	168	177	120	
Manifold	177	123	194	72	183	58	86
50-100 μ							
Pump No. 1	22	7	27	11	25	8	12
Pump No. 1 Drn.	24	49	45	12	18	10	23
Pump No. 2	12	15	21	14	13	11	
Pump No. 2 Drn.	11	18	29	34	20	17	
Manifold	12	16	14	16	21	13	16
> 100 μ							
Pump No. 1	4	1	7	4	2	4	5
Pump No. 1 Drn.	5	16	8	6	2	3	3
Pump No. 2	3	1	4	1	2	4	
Pump No. 2 Drn.	1	3	9	4	3	6	
Manifold	4	4	3	3	3	5	5

B2116

TABLE II

COUNTS AS % OF MANIFOLD COUNT

	0 hrs	9h 22m	17h 32m	25h 37m	32h 32m	40h 37m	49h 2m
10-25 μ							
Pump No. 1	97	84	99	117	96	73	112
Pump No. 1 Drn.	131	133	109	119	110	101	200
Pump No. 2	62	91	78	89	88	89	
Pump No. 2 Drn.	63	127	94	224	93	112	
25-50 μ							
Pump No. 1	102	66	128	153	125	76	48
Pump No. 1 Drn.	176	275	184	193	115	107	187
Pump No. 2	144	62	97	121	92	88	
Pump No. 2 Drn.	68	168	183	233	97	207	
50-100 μ							
Pump No. 1	183	44	193	69	119	61	75
Pump No. 1 Drn.	200	306	321	75	86	77	144
Pump No. 2	100	94	150	87	62	85	
Pump No. 2 Drn.	92	112	207	212	95	131	
> 100 μ							
Pump No. 1	100	25	233	133	66	80	100
Pump No. 1 Drn.	125	400	267	200	66	60	60
Pump No. 2	75	25	133	333	66	80	
Pump No. 2 Drn.	250	73	300	133	100	120	

3.3 In the course of the tests, all pumps exhibited continuous leakage increases to values in excess of .5 gpm. The leakage flows are plotted as a function of cycling time in Graph No. 3. Of the three pumps undergoing test, however, only pump number one (80060) was taken off test for reasons of increased leakage alone.

3.4 Pumps numbers 2 and 3 (serial numbers 80018 and 80062 respectively) showed leakage increases, but, in addition, showed erratic torque traces. The torque trace for pump No. 2 just before shut-off is shown in Figure 3. (Compare with normal trace shown in I-B2116-3, pg. 4, Figure 2.) No. 3 pump was developing the same characteristics just before shut-off as shown in Figure 4. Pump No. 1 appeared to show an erratic trace but to a considerably lesser degree and was allowed to run until the leakage was high. The torque trace for No. 1 pump is shown in Figure 5.

3.5 After the test, the pumps were disassembled and inspected. Considerable amounts of very fine bronze particles and fine AC dust were found in the pump cases, but no visible signs of scoring were observed for pistons, piston barrels, compensators, or bearings. The pump parts were ultrasonically cleaned in Freon and the pumps were then reassembled. A short retest of one hour's duration confirmed the high leakage flows but showed no evidence of the erratic torques. It would appear, since the torque variations were high frequency, that the variations result from the presence of contaminant under the piston shoes or in the bearings. Removal of the contaminant by cleaning does away with the variation.

3.6 Particle counts obtained during the test are listed in Table 3. The counts are expressed as percentages of inlet manifold counts in Table 4 and these values are shown graphically as a function of time in Graph No. 4.

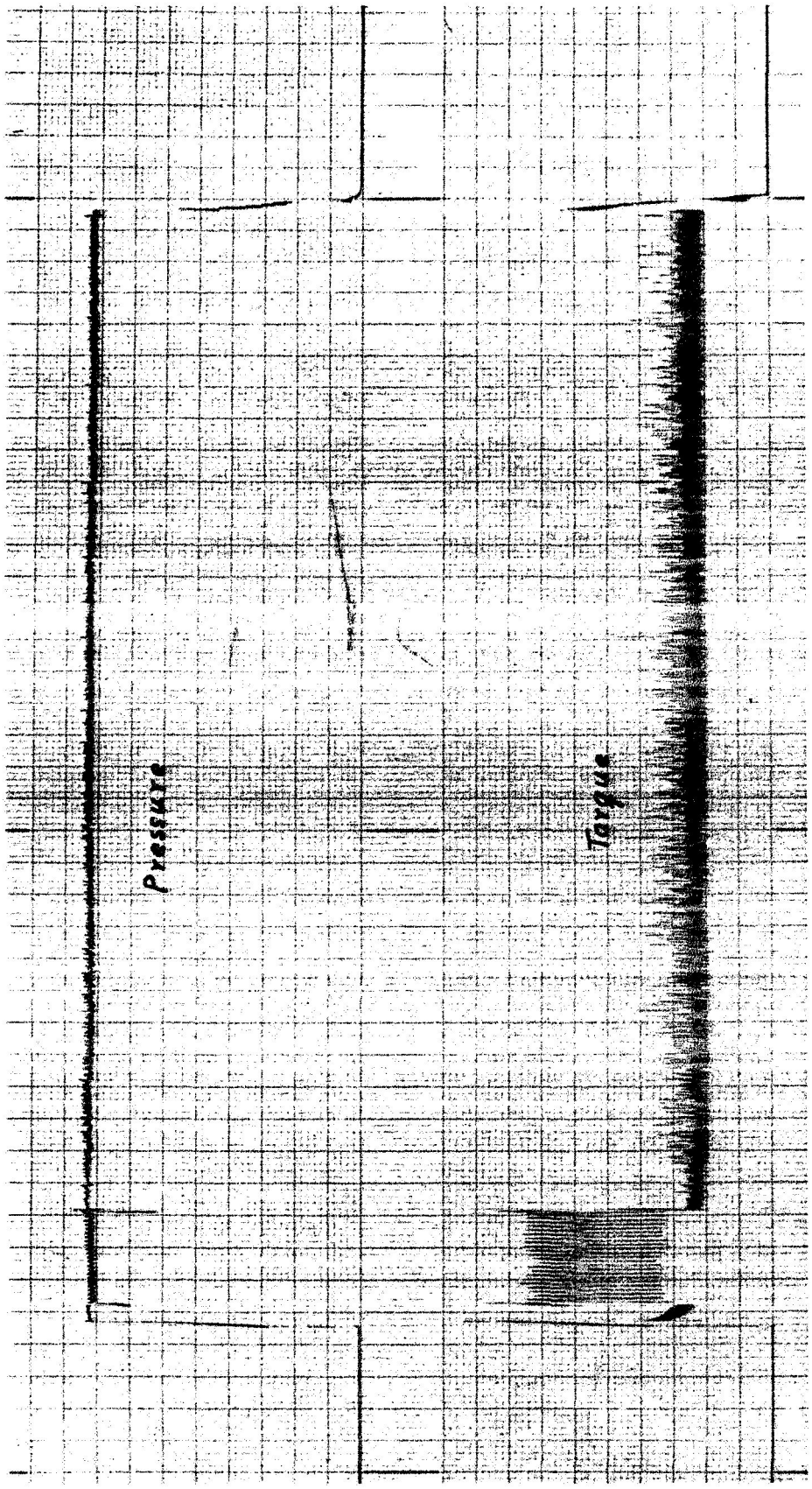


Figure 3

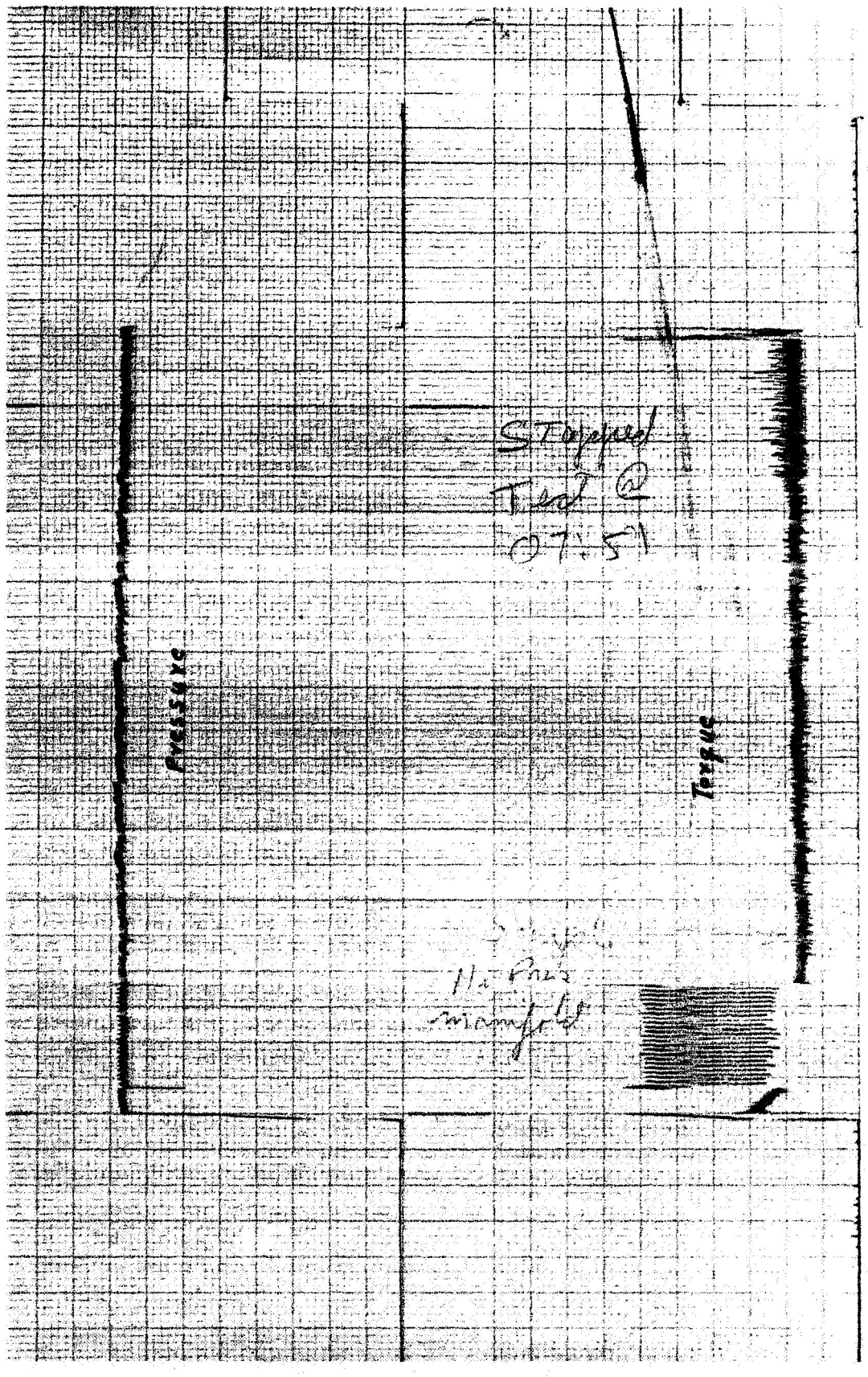


Figure 4

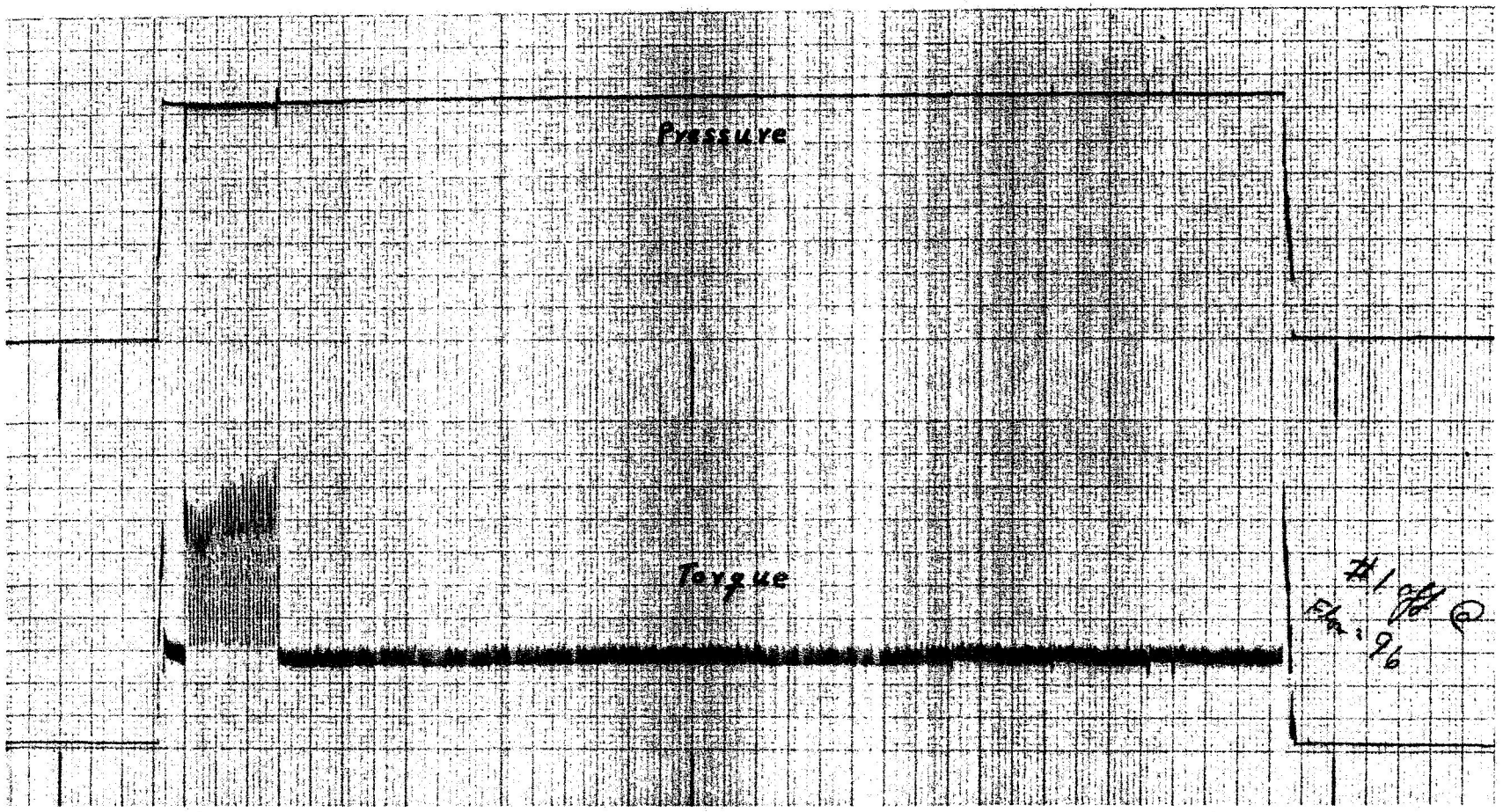
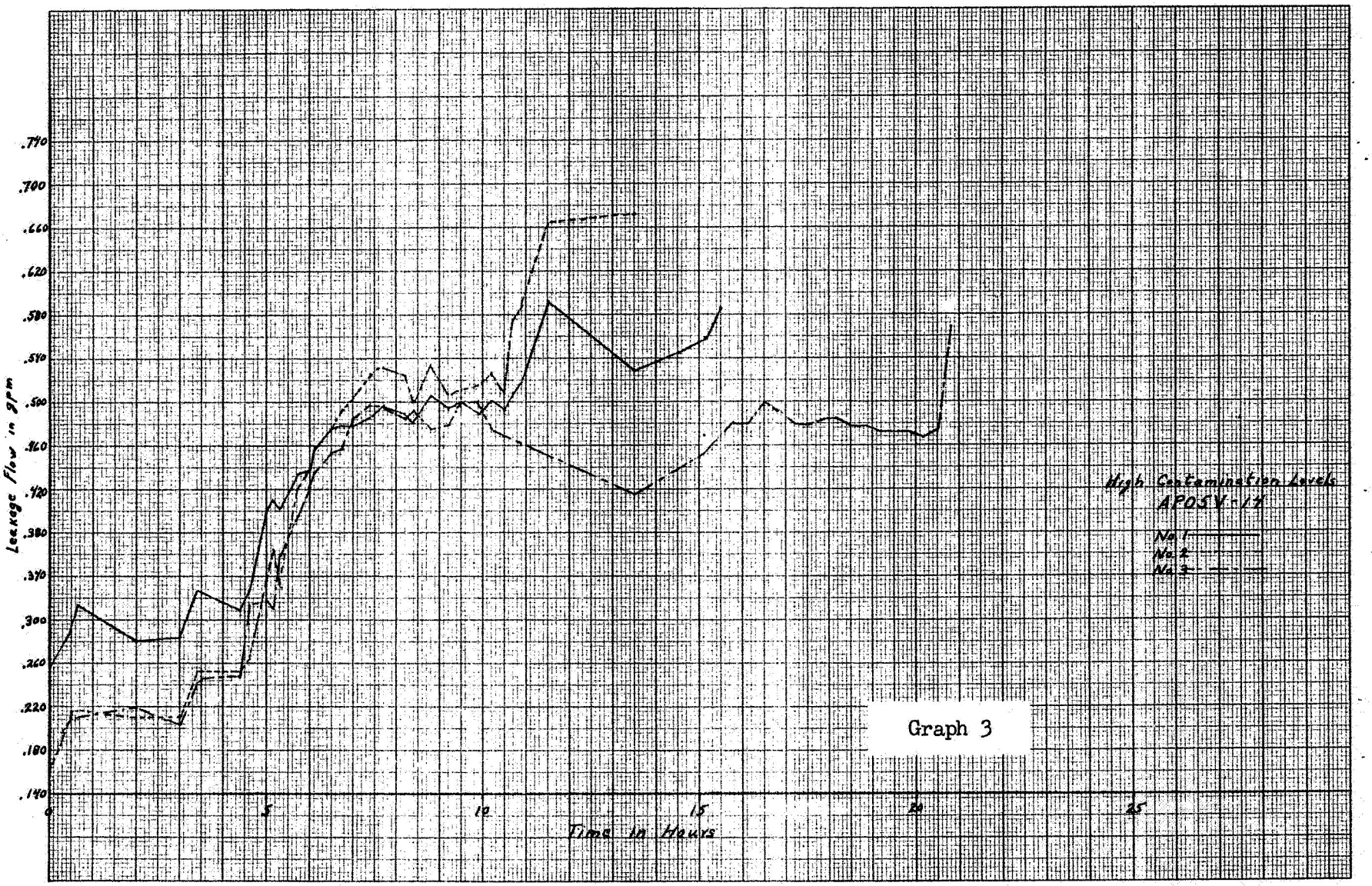


Figure 5


.770
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.220
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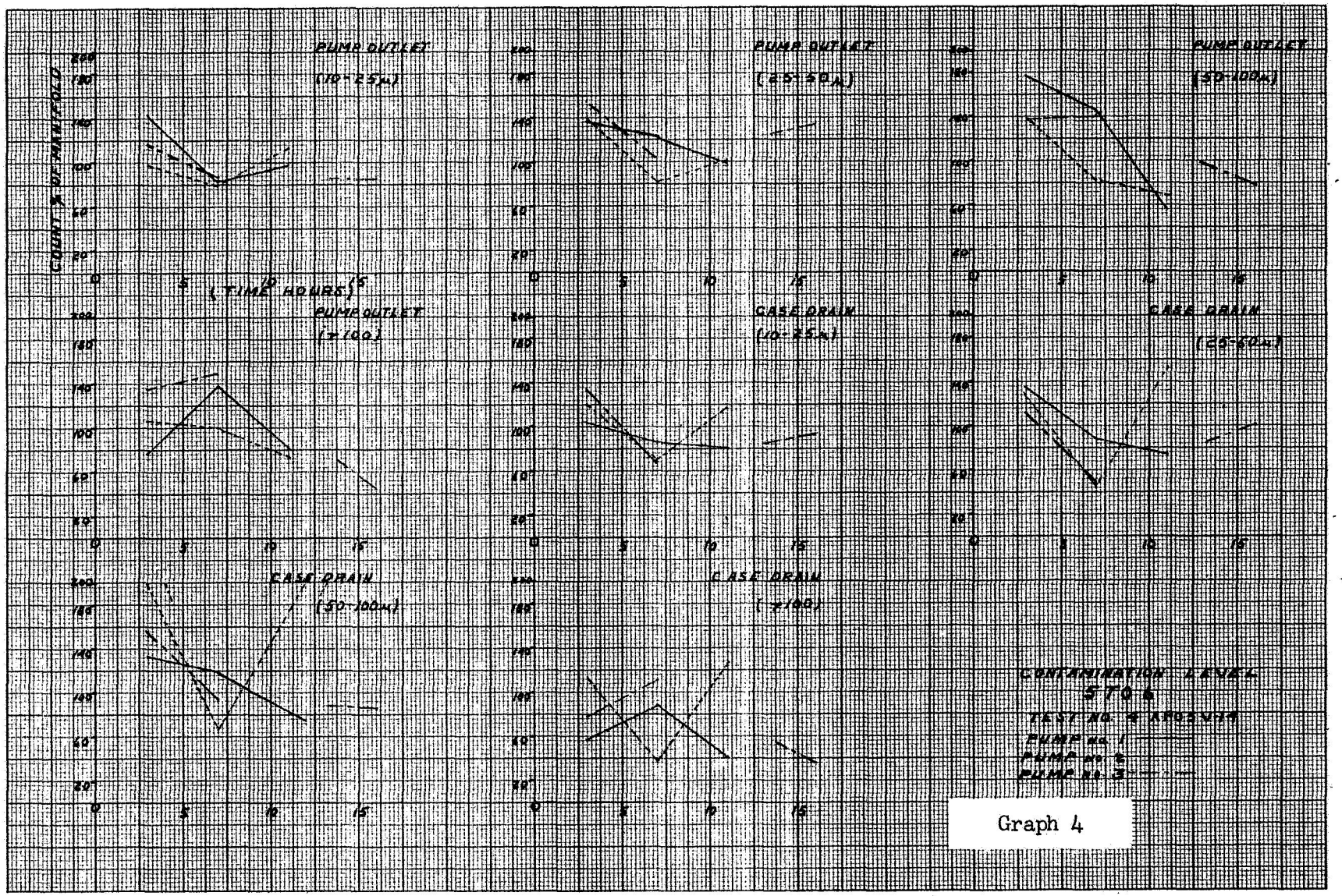
.140
0
5
10
15
20
25
Leakage Flow in gpm
Time in Hours
High Contamination Levels
APOSV-14
No 1
No 2
No 3

Graph 3


PUMP OUTLET
(10-25μ)
PUMP OUTLET
(25-50μ)
PUMP OUTLET
(50-100μ)
CASE DRAIN
(10-25μ)
CASE DRAIN
(25-50μ)
CASE DRAIN
(50-100μ)
CASE DRAIN
(+100)
WEIGHT % OF MANIFOLD
(TIME HOURS)
CONTAMINATION LEVEL
STD 5
TEST NO. 4 ARIZONA
PUMP No. 1
PUMP No. 2
PUMP No. 3

Graph 4

B2116

TABLE 3

PARTICLE COUNTS

	3 hrs.	7 hrs.	11 hrs.	16 hrs.
10-25μ				
Pump No. 1	36,806	46,370	56,146	
Pump No. 1 Drn.	26,667	48,330	46,945	
Pump No. 2	24,452	44,644	65,007	
Pump No. 2 Drn.	30,672	38,936	67,308	
Pump No. 3	24,999	47,712		49,756
Pump No. 3 Drn.	34,591	37,620		54,016
Manifold	25,642	55,550	57,765	57,595
25-50μ				
Pump No. 1	1095	1082	928	
Pump No. 1 Drn.	1099	776	696	
Pump No. 2	1135	715	971	
Pump No. 2 Drn.	1030	483	1465	
Pump No. 3	1252	920		715
Pump No. 3 Drn.	911	426		536
Manifold	807	877	945	528
50-100μ				
Pump No. 1	121	47	36	
Pump No. 1 Drn.	92	38	47	
Pump No. 2	96	27	44	
Pump No. 2 Drn.	144	22	144	
Pump No. 3	93	45		11
Pump No. 3 Drn.	106	30		12
Manifold	68	32	63	14
>100μ				
Pump No. 1	11	11	18	
Pump No. 1 Drn.	8	7	9	
Pump No. 2	15	8	17	
Pump No. 2 Drn.	16	3	28	
Pump No. 3	19	12		5
Pump No. 3 Drn.	11	9		4
Manifold	14	8	22	11

B2116

TABLE 4

COUNTS AS % OF MANIFOLD COUNT

	3 hrs.	7 hrs.	11 hrs.	16 hrs.
10-25μ				
Pump No. 1	144	83	97	
Pump No. 1 Drn.	104	87	81	
Pump No. 2	95	80	113	
Pump No. 2 Drn.	120	70	117	
Pump No. 3	117	86		86
Pump No. 3 Drn.	135	68		94
25-50μ				
Pump No. 1	136	123	98	
Pump No. 1 Drn.	136	88	74	
Pump No. 2	140	82	103	
Pump No. 2 Drn.	128	55	155	
Pump No. 3	155	105	-	135
Pump No. 3 Drn.	112	49		102
50-100μ				
Pump No. 1	178	147	57	
Pump No. 1 Drn.	135	119	75	
Pump No. 2	141	84	70	
Pump No. 2 Drn.	212	69	229	
Pump No. 3	137	141		79
Pump No. 3 Drn.	156	94		86
>100μ				
Pump No. 1	79	138	82	
Pump No. 1 Drn.	57	88	41	
Pump No. 2	107	100	77	
Pump No. 2 Drn.	114	38	127	
Pump No. 3	136	150		45
Pump No. 3 Drn.	79	112		36

3.7 In the course of the tests, difficulty was encountered with one of the 16-120A servo valves. After about 9 hours of testing the servo actuator on which the valve was mounted showed very sluggish response. The valve was removed and subsequent testing in Astrionics Laboratory at MSFC confirmed that the servo-valve was initially sluggish in operation, but the performance improved as the valve was operated in a clean system. Evidently the difficulty resulted from silting, since great numbers of particles below 10 microns dimension were in the system as a consequence of the grinding action of the pumps on the A.C. dust.

4.0 PV006L012B Tests, 3 to 4 Level

4.1 Three PV006L012 pumps which had been satisfactory during tests at a 0 to 1 level were used for these tests. The 3 to 4 test level was selected as an intermediate level. The experience gained during other tests in the series seemed to indicate that this level could be expected to cause difficulty within the time of test. The pumps used were:

	Leakage Flow	
Pump No.	End of 1st Test	Start of This Test*
MX7-4069	.170 gpm	.120 gpm
MX7-4054	.210 gpm	.120 gpm
MX7-4061	.210 gpm	.130 gpm

*Note: 100°F starting temperature

4.2 At the start of the test both No. 1 and No. 2 pump exhibited erratic torque traces, but after several cycles the traces became normal. After approximately four hours of cycling, the torque for No. 2 pump again became suddenly erratic and leakage jumped from .265 gpm

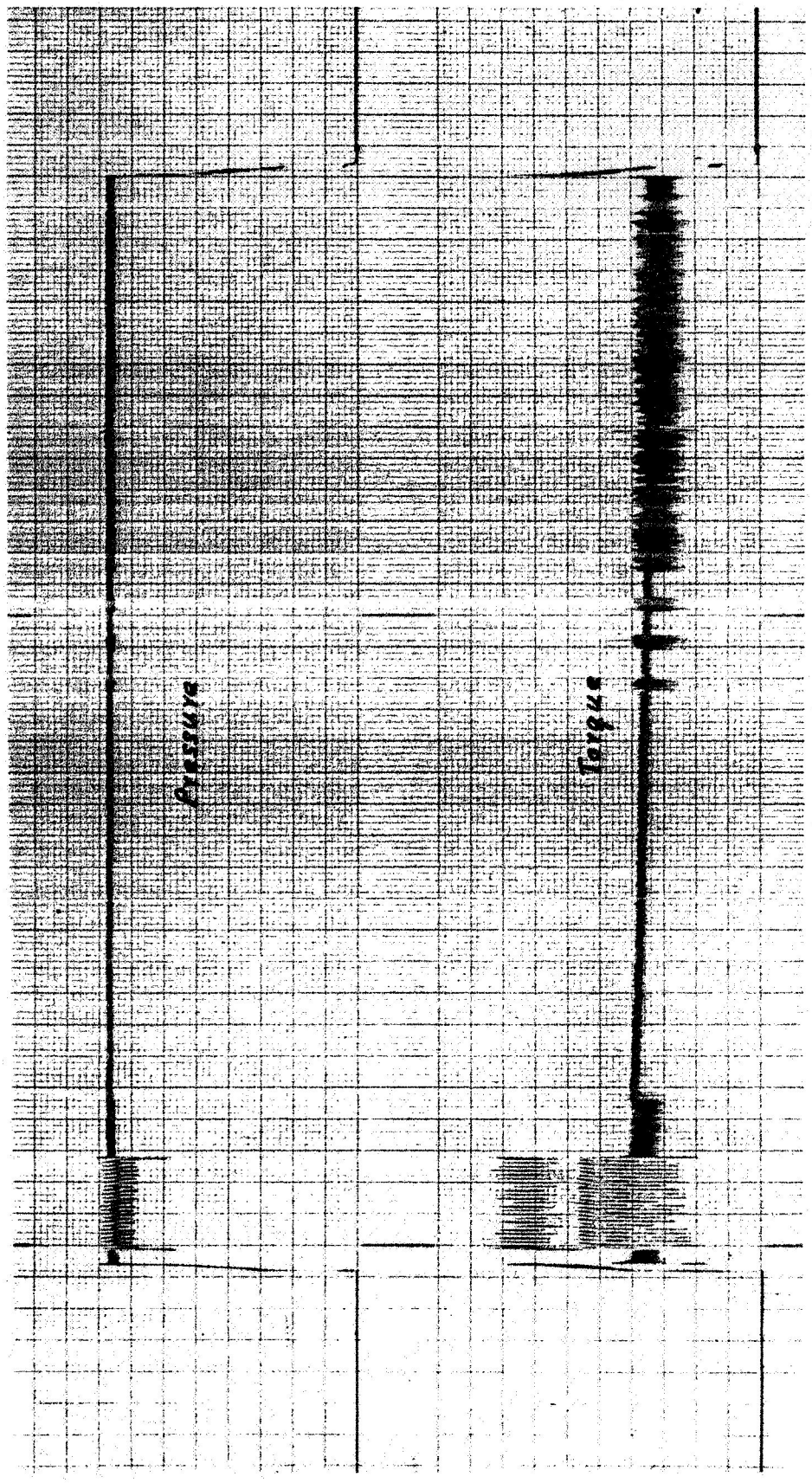


Figure 6

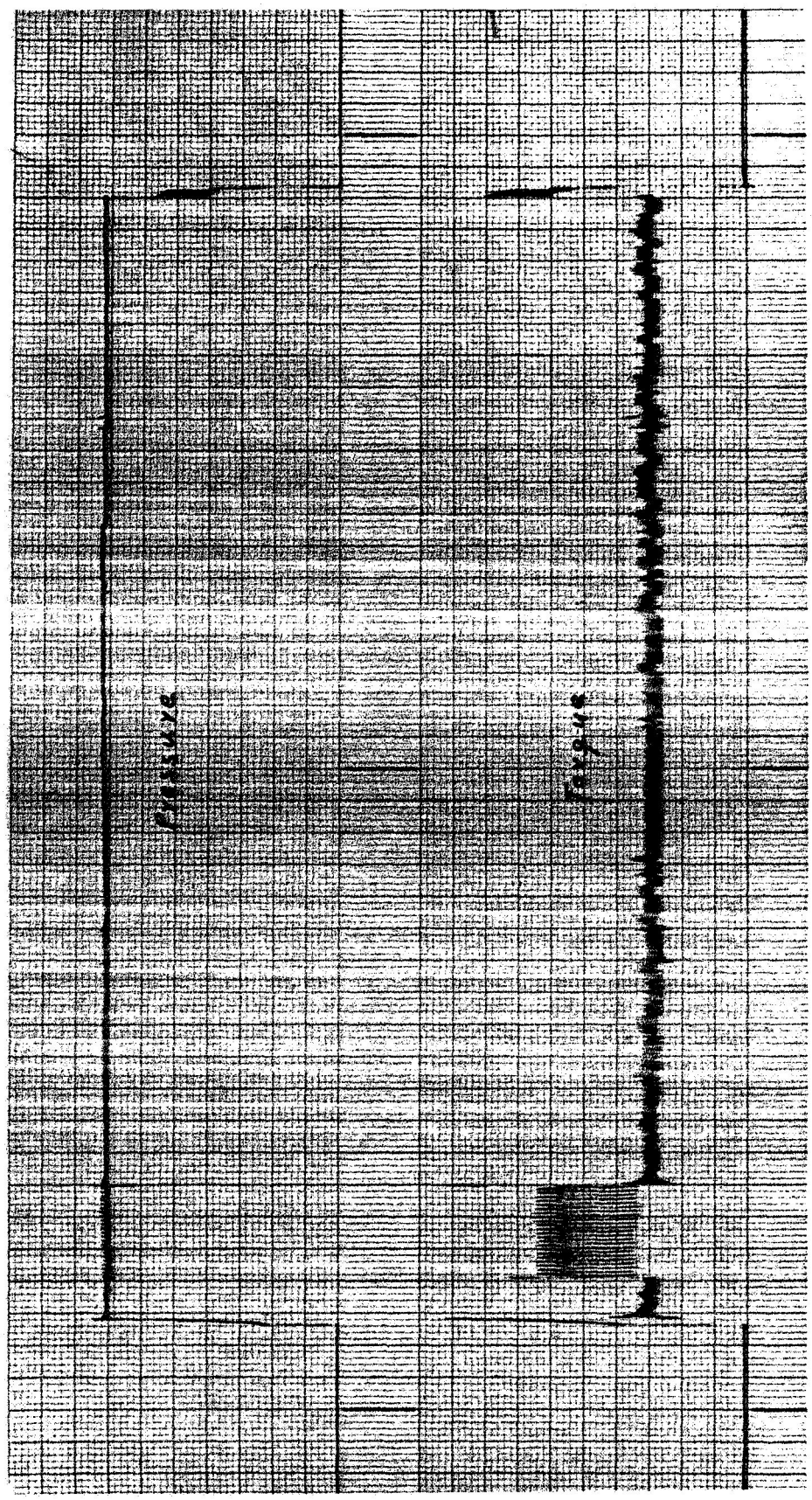


Figure 7

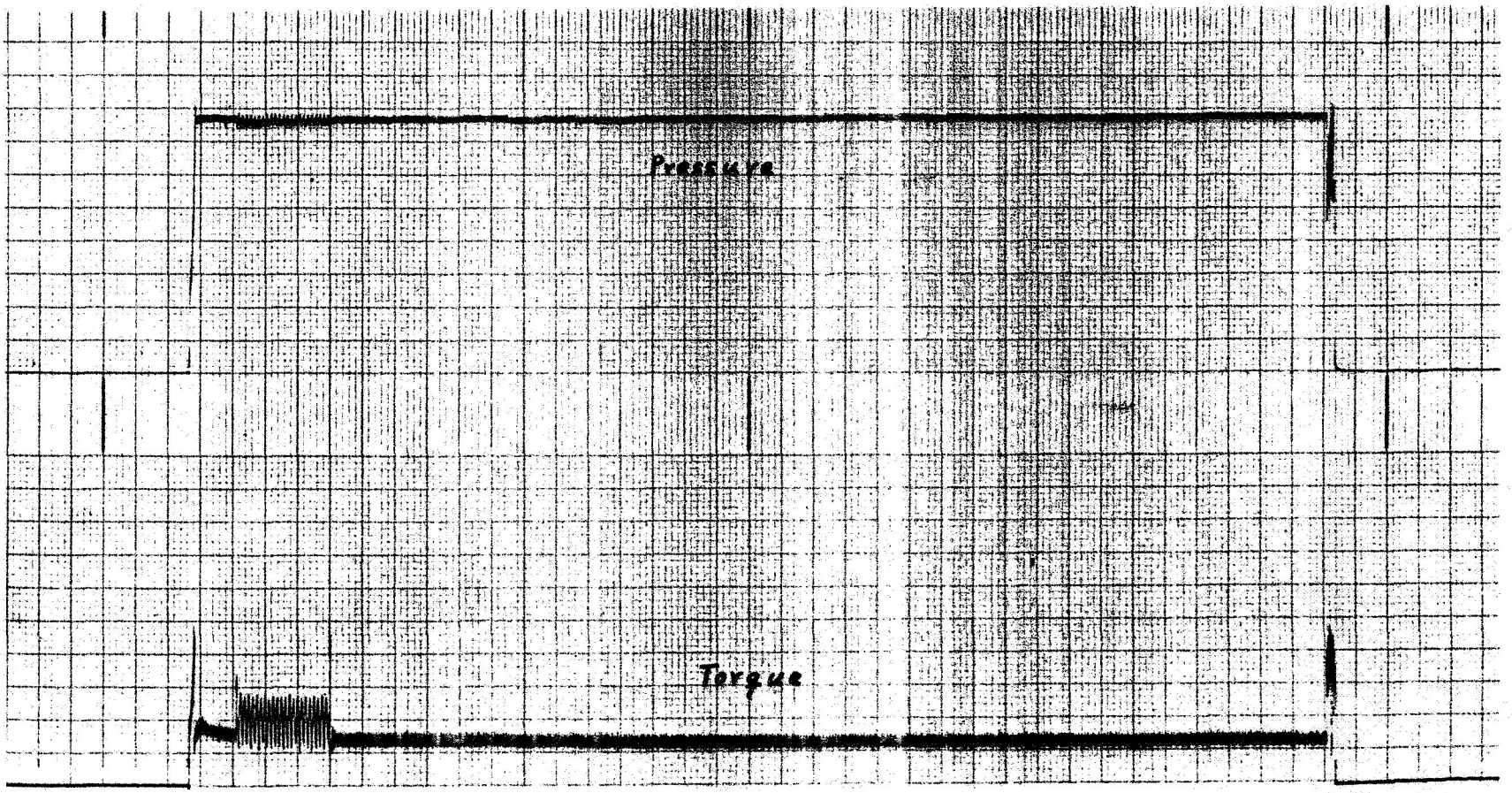
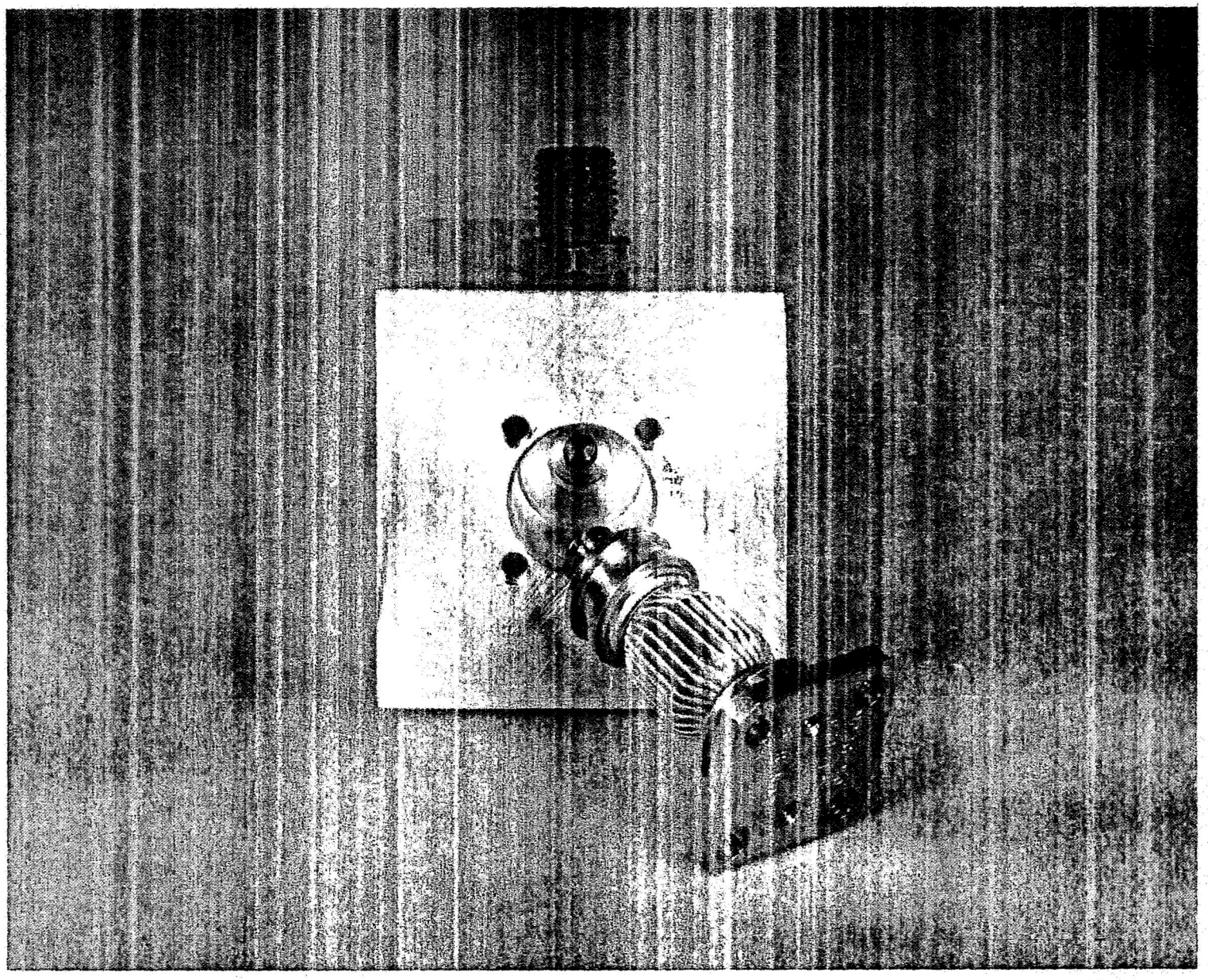


Figure 8



NOT REPRODUCIBLE

Figure 9

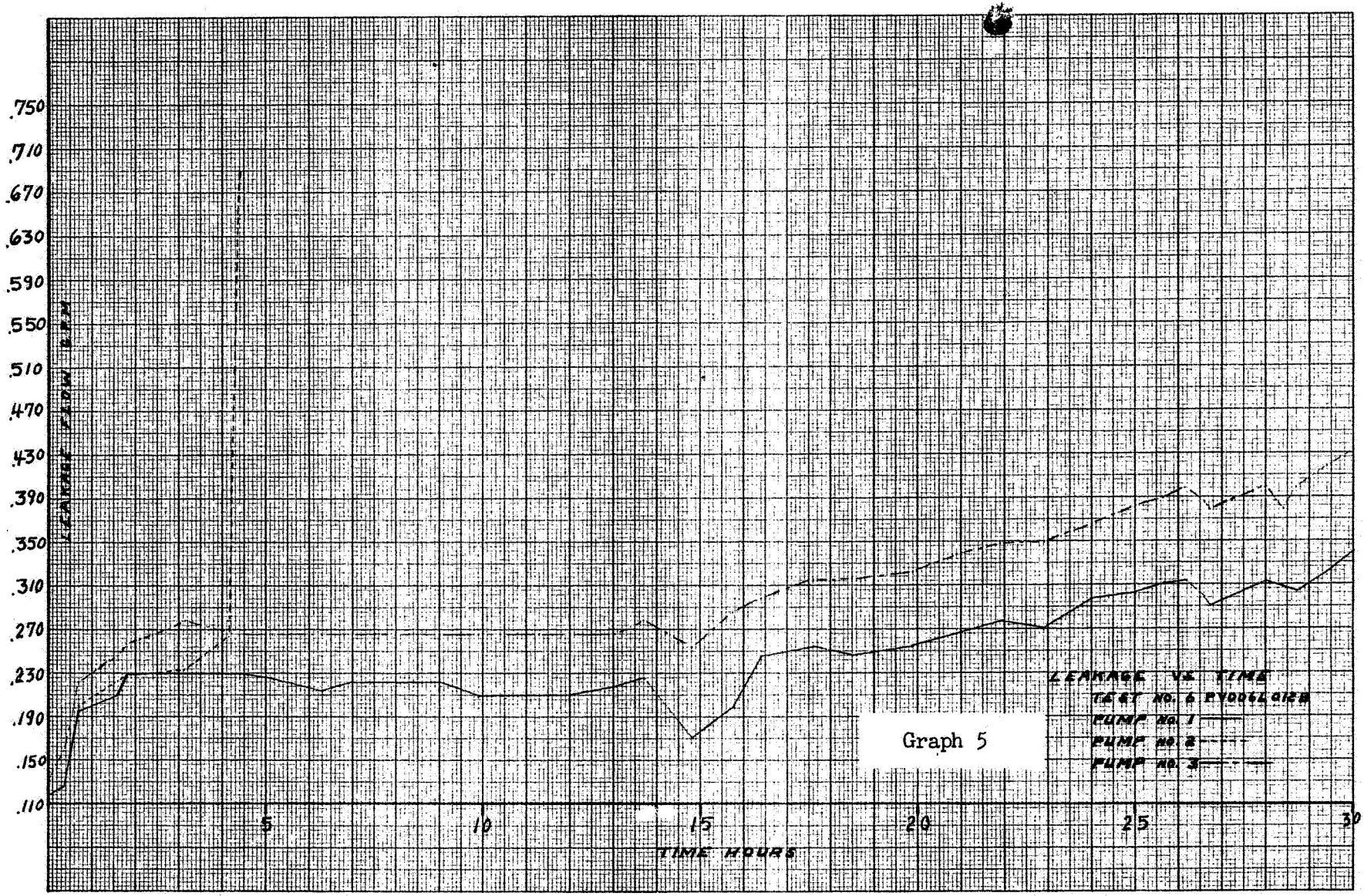
to .690 gpm. The pump was taken off test immediately. The erratic trace for the pump is shown in Figure 6. Tests were discontinued on No. 1 and No. 3 pumps when the leakage flows reached .340 gpm and .430 gpm respectively. This was done to prevent further damage to the pumps. The torque traces for these pumps just prior to shut off are shown in Figures 7 and 8 respectively and the leakage flows are shown plotted as a function of cycling time in Graph No. 5. No. 2 pump will be inspected to determine the cause of failure.

4.3 Table 5 shows the contamination counts made in the course of the test. Table 6 shows the counts as the percentage of inlet manifold counts and these values are plotted as a function of time in Graph No. 6.

5.0 Filter Tests

5.1 Life and efficiency tests were carried out on the S-IV servo-actuator filters. Two filters (S/N7 and S/N14) were used for these tests. The filters were cleaned before each subsequent use. The tests consisted of placing the filter in a housing exactly simulating the actuator housing. (Figure 9.) The unit was constructed according to Moog Servocontrols Inc. print No. 033-13178. The change in pressure drop across the filter and housing was observed while known quantities of AC Course Test Dust were added to the system at 15 minute intervals. The system flow was one gallon per minute, the maximum rated flow of the filters, and the allowable increase in ΔP was arbitrarily selected as 25 psi.

5.2 Graph No. 7 shows the time required to attain the 25 psi ΔP increase as a function of the AC dust addition rate in grams per 15 minutes. An add rate of .005 grams per 15 minutes corresponds fairly closely to a maintained ASTM No. 2 level. The time value at this point (by extrapolation) is approximately four hours.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.270
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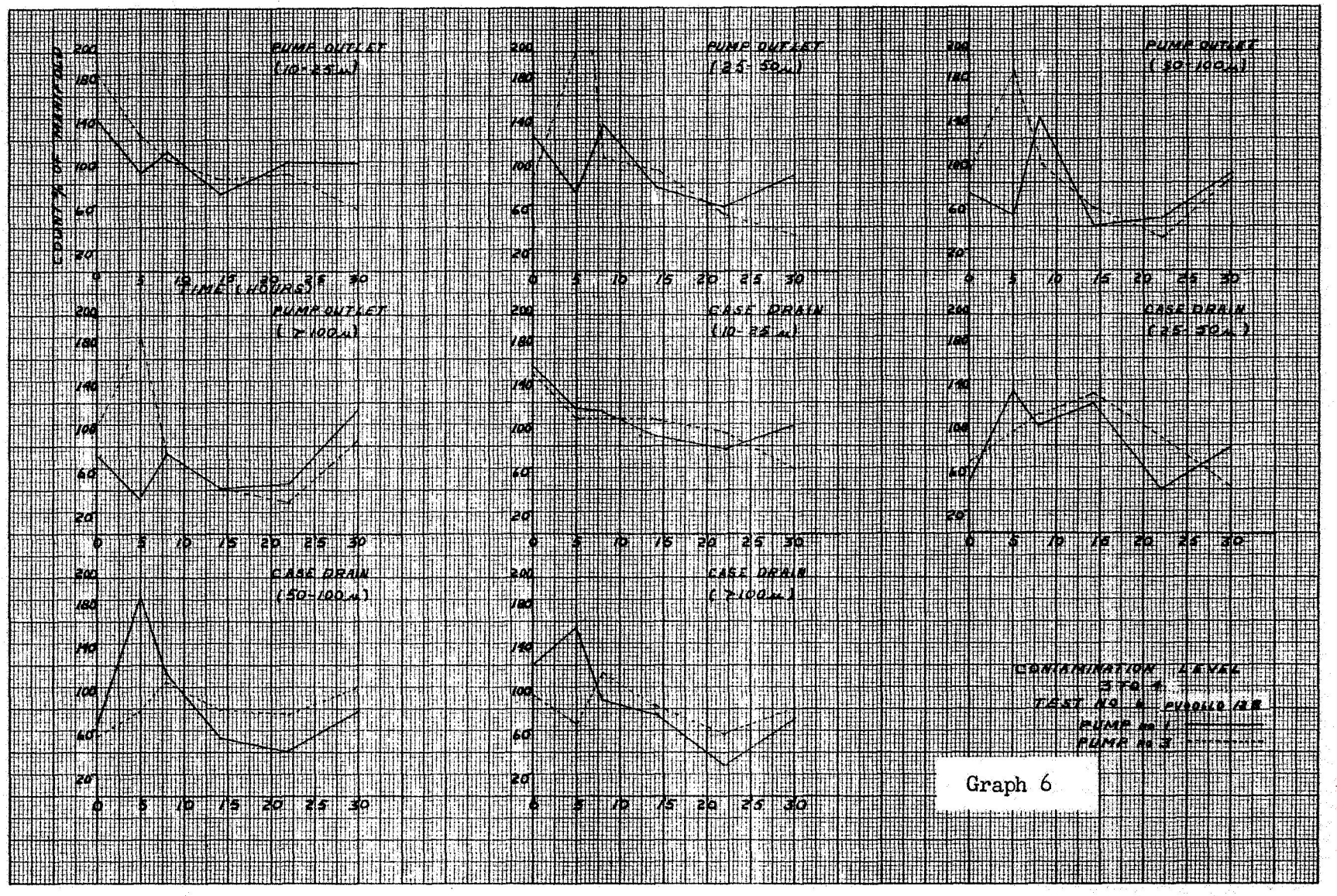
15
20
25
30
TIME HOURS
LEAKAGE VS TIME
TEST NO. 6 HYDROLAZER
PUMP NO. 1
PUMP NO. 2
PUMP NO. 3

Graph 5


CONTAMINATION LEVEL
PUMP OUTLET (10-25 μ)
PUMP OUTLET (25-50 μ)
PUMP OUTLET (50-100 μ)
PUMP OUTLET (> 100 μ)
CASE DRAIN (10-25 μ)
CASE DRAIN (25-50 μ)
CASE DRAIN (50-100 μ)
CASE DRAIN (> 100 μ)
TIME (HOURS)
0 5 10 15 20 25 30
20 40 60 100 140 180 200
CONTAMINATION LEVEL
3 TO 4
TEST NO 4 PVB20LD (RE
PUMP NO 1
PUMP NO 3

Graph 6

B2116

Table 5

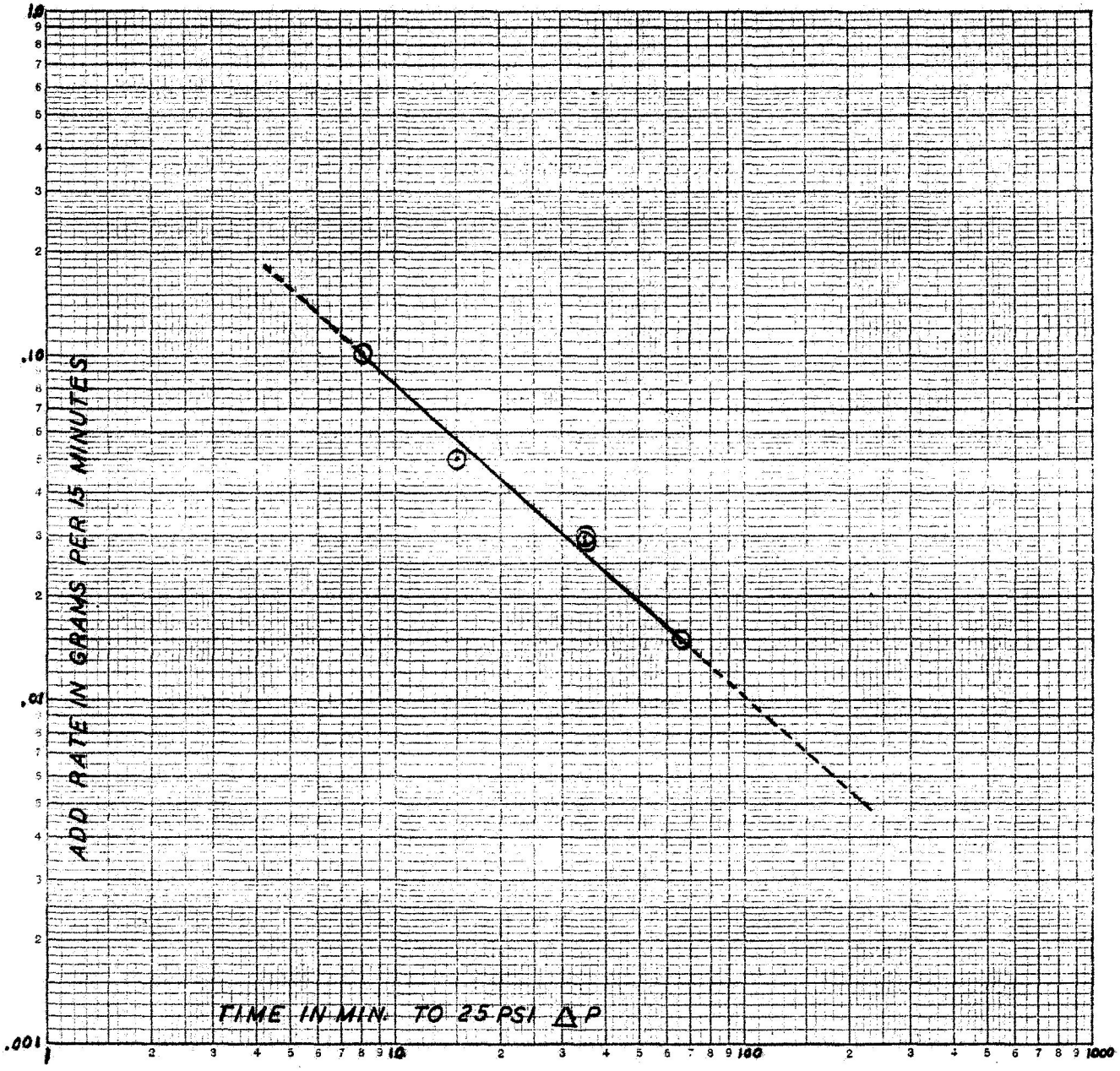
PARTICLE COUNTS

	0 hrs	5 hrs	8 hrs	14½ hrs	22 hrs	30 hrs
10-25 μ						
Pump No. 1	23,680	29,479	32,716	20,877	36,672	24,282
Pump No. 1 Drn.	25,900	37,743	32,035	26,156	28,882	24,407
Pump No. 2	22,066					
Pump No. 2 Drn.	18,744					
Pump No. 3	30,586	40,214	29,308	24,537	32,631	13,887
Pump No. 3 Drn.	24,367	34,024	29,905	30,672	33,228	14,824
Manifold	16,784	32,376	28,391	29,308	36,550	24,708
25-50 μ						
Pump No. 1	1,705	471	492	443	579	604
Pump No. 1 Drn.	721	860	570	690	417	528
Pump No. 2	1,090					
Pump No. 2 Drn.	833					
Pump No. 3	11,67	1,516	594	545	511	231
Pump No. 3 Drn.	917	608	630	741	869	291
Manifold	1,380	664	579	579	988	681
50-100 μ						
Pump No. 1	92	21	32	20	31	24
Pump No. 1 Drn.	86	87	26	26	26	21
Pump No. 2	88					
Pump No. 2 Drn.	56					
Pump No. 3	118	88	22	28	20	23
Pump No. 3 Drn.	72	38	24	38	48	27
Manifold	130	48	23	49	64	27
>100 μ						
Pump No. 1	11	3	6	5	8	8
Pump No. 1 Drn.	18	14	7	9	5	5
Pump No. 2	10					
Pump No. 2 Drn.	13					
Pump No. 3	15	16	6	5	5	6
Pump No. 3 Drn.	14	6	9	10	11	7
Manifold	15	9	8	12	17	7

B2116

Table 6

	COUNTS AS OF MANIFOLD COUNT					
	0 hrs	5 hrs	8 hrs	14½ hrs	22 hrs	30 hrs
10-25 μ						
Pump No. 1	141	91	115	71	100	98
Pump No. 1 Drn.	154	117	113	89	79	99
Pump No. 2	131					
Pump No. 2 Drn.	112					
Pump No. 3	182	124	103	84	89	56
Pump No. 3 Drn.	145	105	105	105	91	60
Manifold						
25-50 μ						
Pump No. 1	124	71	137	77	59	89
Pump No. 1 Drn.	52	130	98	119	42	78
Pump No. 2	79					
Pump No. 2 Drn.	60					
Pump No. 3	85	228	103	94	52	34
Pump No. 3 Drn.	66	92	109	128	88	43
Manifold						
50-100 μ						
Pump No. 1	71	51	139	41	48	89
Pump No. 1 Drn.	66	181	113	53	41	78
Pump No. 2	68					
Pump No. 2 Drn.	44					
Pump No. 3	91	183	96	57	31	85
Pump No. 3 Drn.	55	79	104	79	75	100
Manifold						
>100 μ						
Pump No. 1	73	33	75	42	47	114
Pump No. 1 Drn.	120	155	88	75	29	71
Pump No. 2	66					
Pump No. 2 Drn.	87					
Pump No. 3	100	178	75	42	29	86
Pump No. 3 Drn.	93	67	113	83	58	100
Manifold						


ADD RATE IN GRAMS PER 15 MINUTES
TIME IN MIN. TO 25 PSI ΔP
.001
.01
.10
1
10
100
1000

Graph 7

Table 7

	Start		End		% Particles Passed	
	Upstream	Downstream	Upstream	Downstream	Start	End
S/N 7						
10-25μ	40470	31438	50580	25500	77.7	46.5
25-50μ	3442	2266	12880	2362	65.8	18.3
50-100μ	478	292	1320	179	61.1	13.6
>100μ	50	37	361	45	74.0	12.5
S/N 7						
10-25μ	24878	14800	17721	10564	59.4	59.6
25-50μ	1584	1121	1496	707	70.7	47.2
50-100μ	202	56	124	58	27.7	46.7
>100μ	24	9	26	12	37.5	46.2
S/N 7						
10-25μ	27349	16273	24196	16188	59.5	66.9
25-50μ	2368	973	1635	875	41.0	53.5
50-100μ	196	52	134	47	26.5	35.0
>100μ	34	11	35	19	32.3	54.2
S/N 14						
10-25μ	17806	11928	31950	17040	66.9	53.3
25-50μ	1593	485	2982	621	30.4	20.8
50-100μ	248	61	554	90	24.5	16.2
>100μ	46	21	76	12	45.6	15.7
S/N 14						
10-25μ	14313	9372	11161	7156	65.4	64.1
25-50μ	1209	604	1005	664	49.9	66.0
50-100μ	95	43	107	38	46.2	35.5
>100μ	32	16	18	7	50.0	38.8

5.3 Table 7 shows the percentage of particles impinging on the filter which apparently passed through the filter. The upstream and downstream counts were taken at the beginning of the test run and again when the change in ΔP reached 25 psi.

6.0 The final data analysis for the pump tests is in progress. Tests of the S-IV system will be completed.

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Approved by

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